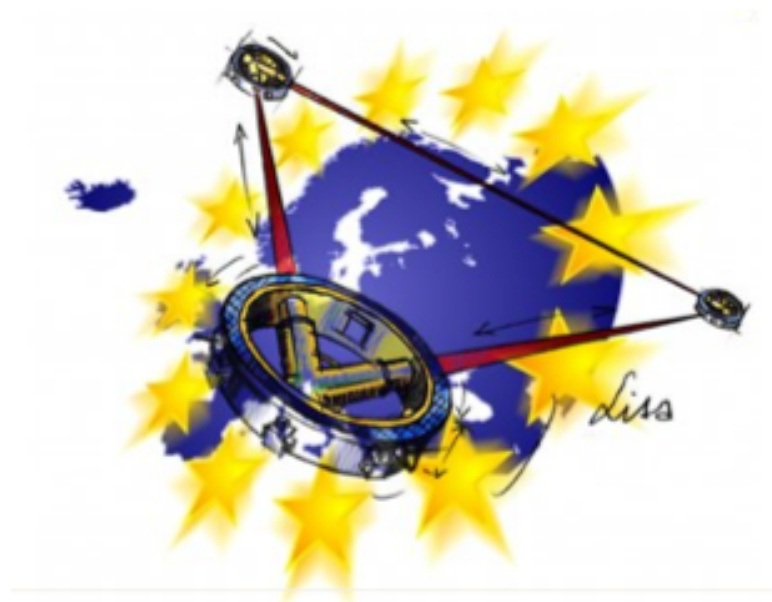


# Status of Space-based Gravitational-wave Observatories (SGOs)



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**NASA Goddard Space Flight Center**  
**Jeffrey.Livas@nasa.gov**

# Outline

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- **What happened to LISA?**
- **Context and status of e(volved)LISA**
- **Context and status of SGO-Mid**
- **Science**
- **Summary**

- 13
- <sup>th</sup>
- International Conference on TAUP 8-13 Sep 2013

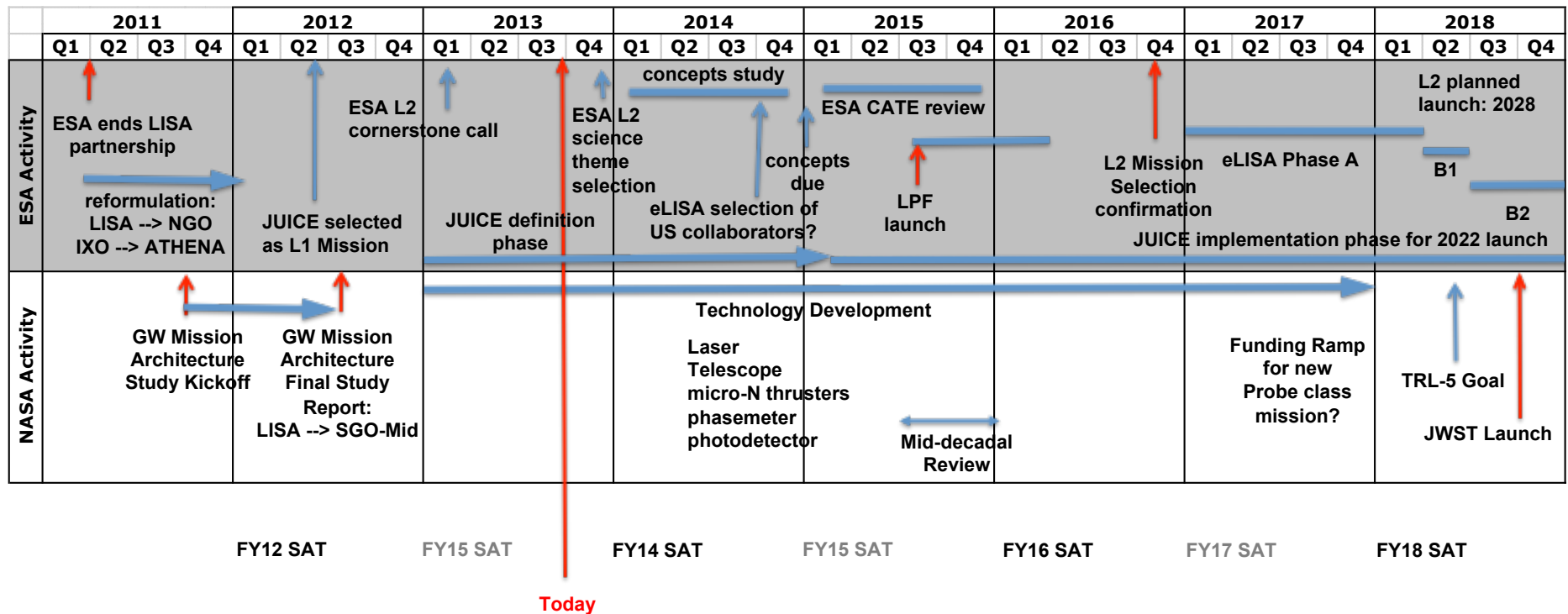
# **Context and Status of eLISA/NGO (1)**

- **Not selected for L1 (JUICE is the L1 mission)**
- **No official eLISA/NGO project office at ESA**
  - Concept Study team would be re-established by L2 selection
- **Substantial investment in LISA Pathfinder**
  - July 2015 launch expected
  - Results known before final L2 selection (expected Feb 2016)
- **Strong consortium of European researchers and institutes in ESA member states**
  - Currently maturing science case and mission concept
  - Includes technology development funding of ? \$M/yr
- **ESA technology development of ~ \$10M/yr (legacy)**
  - Will continue until current contracts are completed

## Context and Status of eLISA/NGO (2)

- **Strong candidate for L2/L3 Cosmic Visions**
  - Whitepaper: <https://www.elisascience.org/whitepaper/>
  - Presentation 4 Sep 2013 in Paris by K. Danzmann
- **Cost cap for ESA cost is €1000M**
  - Includes satellite platform with telescope, laser, structure
- **Member state contributions of ~ €250M**
  - Instrument “guts” including optical bench with inertial sensor and phasemeter
- **International partner contributions of ~ 20% allowed**
  - ~ €250M (~ \$325M) but Europe must have capability
  - must add to science: enable 3<sup>rd</sup> arm?
- **L2 *mission* selection Feb 2016 for a 2028 launch**

# One possible timeline...



## Assumptions

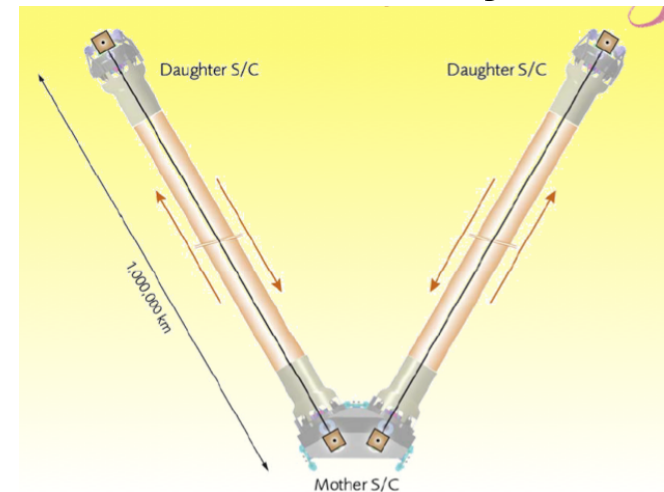
- ESA-led L2 mission
- US minority-level contribution
  - No detailed guidance on what to supply

**A LIGO or PTA detection mid-decade could change this picture!**

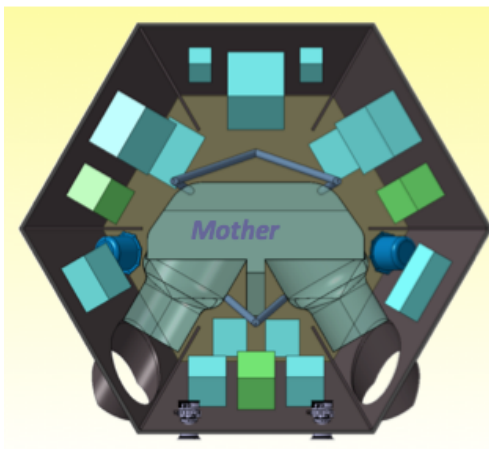
# eLISA/NGO Summary

- **Mission Design**
  - $10^6$  km arm-length, 2 arms, 60 deg “V”
  - Mother + 2 x daughter S/C configuration
  - LISA-like payload
    - 20 cm telescope/2W laser
  - 10-degree drift away heliocentric orbit
  - Launch to sub-GTO, separate from LV
    - Two Soyuz-FRG or
    - shared Ariane V
  - Baseline 2 year lifetime + 2 years
    - Limited by communications bandwidth

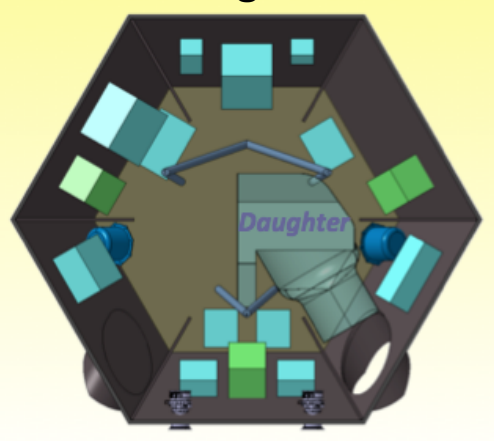
## eLISA/NGO Layout



### Mother

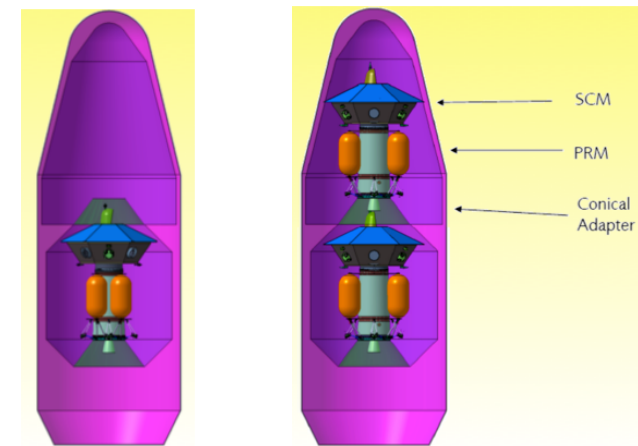


### Daughter



Figures from K. Danzmann ESA presentation

## Soyuz Launch Stack



### Mother

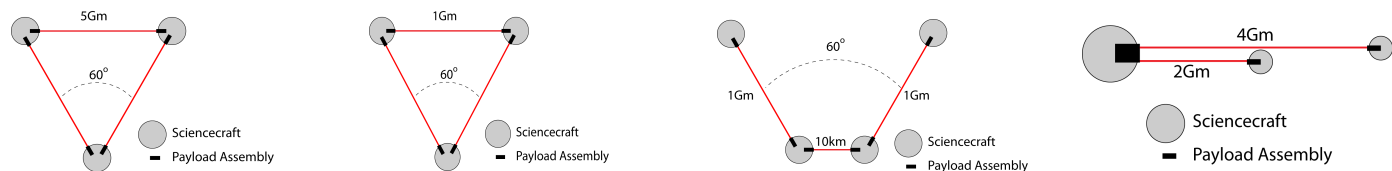
### 2 Daughters

# Context and Status of SGO-Mid

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- **No official project office at NASA**
  - “study” team under Physics of the Cosmos Program office
- **No LISA International Science Team (LIST)**
  - University engagement is critical
- **Technology development for L2 mission contribution**
  - laser                                      -- photoreceiver
  - telescope                                      -- micro-newton thruster
  - phasemeter
- **Participation on LPF science team**
  - ST-7 experiments                      -- mission data analysis operations
- **Developing a reference mission and science case**

# SGO Mission Concepts



Parameter	SGO High	SGO Mid	SGO Low	SGO Lowest
Arm length (meters)	$5 \times 10^9$	$1 \times 10^9$	$1 \times 10^9$	$2 \times 10^9$
Constellation	Triangle	Triangle	Triangle (60-deg Vee)	In-line: Folded SyZyGy
Orbit	22° heliocentric, earth-trailing	9° heliocentric, earth drift-away	9° heliocentric, earth drift-away	≤9° heliocentric, earth drift-away
Trajectory	Direct injection to escape, 14 months	Direct injection to escape, 17 months	Direct injection to escape, 17 months	Direct injection to escape, 18 months
Interferometer configuration	3 arms, 6 links	3 arms, 6 links	2 arms, 4 links	2 unequal arms, 4 links
Launch vehicle	Medium EELV (e.g., Falcon Heavy shared launch)	Medium EELV (e.g., Falcon 9 Block 3)	Medium EELV (e.g., Falcon 9 Heavy shared launch)	Medium EELV (e.g., Falcon 9 Block 2)
Baseline/Extended Mission Duration (years)	5/3.5	2/2	2/2	2/0
Telescope Diameter (cm)	40	25	25	25
Laser power out of telescope end of life (W)	1.2	0.7	0.7	0.7
Measurement system modifications	Baseline/Reference (Same as LISA Concept)	In-field guiding, UV-LEDs, no pointing	4 identical spacecraft with one telescope each, In-field guiding, free space backlink, UV-LEDs, arm locking	3 spacecraft with one telescope each, episodic thrusting, in-field guiding, next gen micronewton thrusters, no prop module
Motivation:	LISA performance with all known economies	lowest cost 6 links	Lowest cost with viable science return	Lowest Cost
Estimated Cost (\$B)	1.66	1.40	1.41	1.19

# Comparison of Mission Concepts Formally Studied

## Science return, risk, and cost

Science Performance	SGO High	SGO Mid	LAGRANGE/ McKenzie	OMEGA Option 1	OMEGA Option 2
Massive Black Hole Binaries					
Total detected	108–220	41–52	37–45	21–32	21–32
Detected at $z \geq 10$	3–57	1–4	1–5	1–6	1–6
Both mass errors $\leq 1\%$	67–171	18–42	8–25	11–26	11–26
One spin error $\leq 1\%$	49–130	11–27	3–11	7–18	7–18
Both spin errors $\leq 1\%$	1–17	<1	0	<1	<1
Distance error $\leq 3\%$	81–108	12–22	2–6	10–17	10–17
Sky location $\leq 1 \text{ deg}^2$	71–112	14–21	2–4	15–18	15–18
Sky location $\leq 0.1 \text{ deg}^2$	22–51	4–8	$\leq 1$	5–8	5–8
Total EMRIs detected <sup>†</sup>	800	~35	~20	~15	~15
WD binaries detected (resolved)	$4 \times 10^4$	$7 \times 10^3$	$5 \times 10^3$	$5 \times 10^3$	$5 \times 10^3$
WD binaries with 3D location	$8 \times 10^3$	$8 \times 10^2$	$3 \times 10^2$	$1.5 \times 10^2$	$1.5 \times 10^2$
Stochastic Background Sensitivity (rel. to LISA)	1.0	0.2	0.15*	0.25	0.25
Top Team X Risk	Moderate <sup>‡</sup>	Low	Moderate	Moderate	High
Top Team X + Core Team Risk	Moderate <sup>‡</sup>	Low	High	High	High
Team X Cost Estimate (FY 12\$)	2.1B	1.9B	1.6B	1.4B	1.2B

<sup>†</sup> Based on median rate; estimates for EMRI rates vary by as much as an order of magnitude in each direction.

\* Two-arm instruments such as LAGRANGE/McKenzie lack the "GW null" channel that can be used to distinguish between stochastic backgrounds & instrumental noise, making such measurements more challenging.

<sup>‡</sup> The moderate risk for SGO High comes about from the thruster development necessary to demonstrate the required lifetime for 5 years of science operations.

Details: <http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php>

# eLISA/NGO Science Performance

Sources	eLISA	LISA
Galactic binaries	~ 3,000	> 20,000
Verification binaries	4	7
Massive Black Hole Binaries	34	Hundreds
Mean MBH mass uncertainty	0.1%	0.01%
Mean sky position uncertainty	TBD	30 arc min
Luminosity distance uncertainty, $Z \sim 5$	100%	20%
Extreme Mass Ratio Inspirals (EMRIs)	Tens	thousands

## Notes:

1. Performance estimates extracted from the L2/L3 whitepaper <https://www.elisascience.org/whitepaper/>
2. Science performance is a complex function of instrument performance, requiring extensive calculations not yet completed
3. Including additional waveform physics will likely increase performance
4. Projected performance of LISA-like detectors has been increasing for several years as additional physics has been included in waveforms.
5. Anticipated improvements in performance calculations should lead to better performance
6. Two arms instead of three has several immediate effects:
  1. no Sagnac mode, which allows instrument noise estimation
  2. loss of instantaneous polarization information
  3. Requires higher reliability for the existing links

# Summary

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- **Space-based gravitational-wave work continues**
  - Science receives top ratings in reviews
  - LPF is progressing for launch in July 2015
  - Issue is funding, not technology
- **Best near term opportunity is minority-level partnership with ESA on an L2 mission**
  - 20+ year scientific collaboration on both sides of the Atlantic
- **Successful LISA Pathfinder technology demo required for L2 selection**
- **US technology development targeted at TRL-5 level for ~ 2018 for key technologies**

# Welcome to the 10th International LISA Symposium

University of Florida, Gainesville, Florida USA  
May 18 - May 23, 2014

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**Home**

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**Registration** - will come soon

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**Program** - will come soon

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**Accommodations**

A block of rooms has been reserved at the Hilton Conference Center. Please make reservations together with registration.

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**Social Event**

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**Contact:**

[lisasymposium@phys.ufl.edu](mailto:lisasymposium@phys.ufl.edu)

00296

[www.hitwebcounter.com](http://www.hitwebcounter.com)



*Image credit: NASA/JPL*

**Welcome to the LISA Symposium X website.**

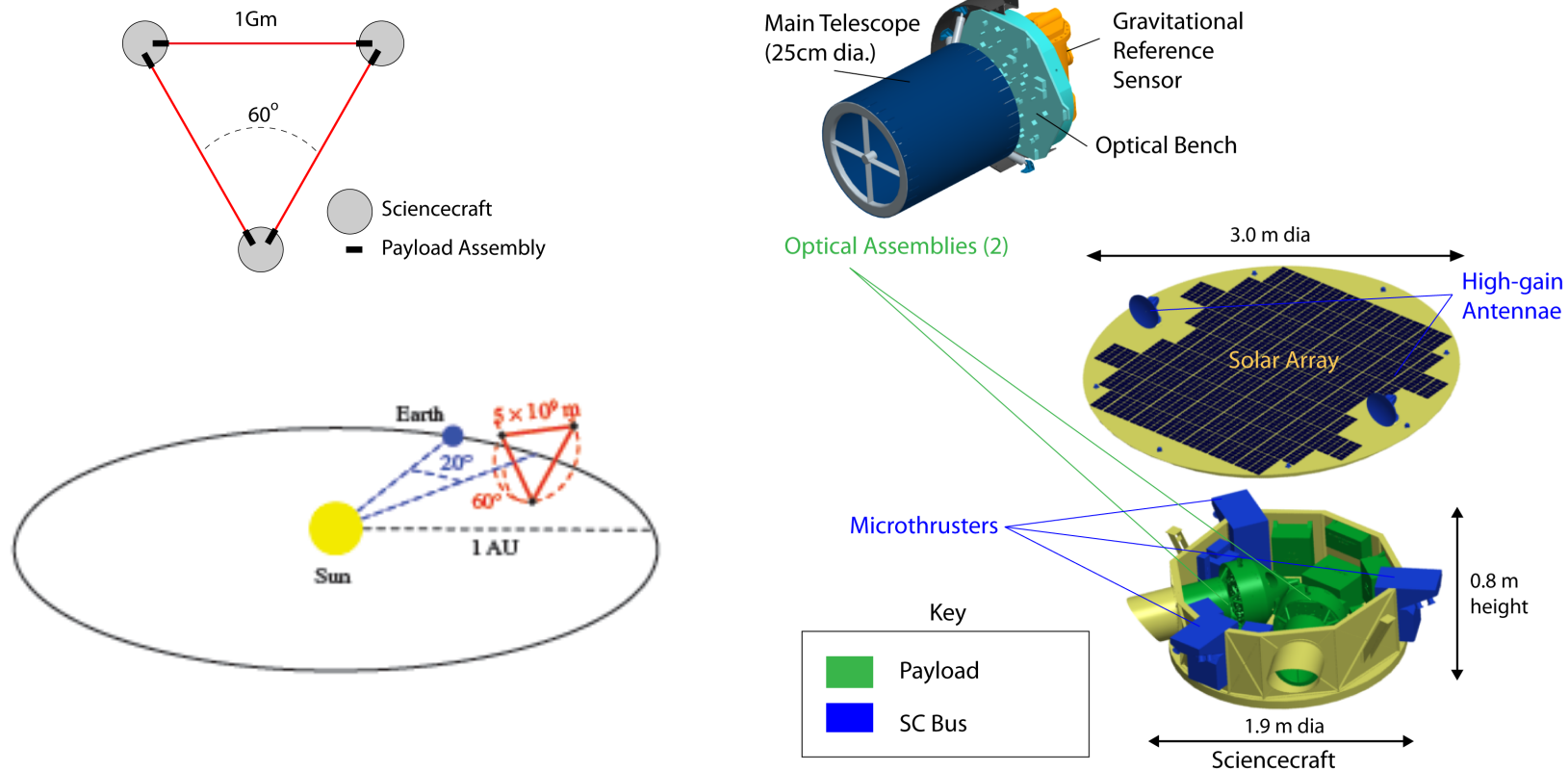
The 10th International LISA Symposium will be held at the **Hilton Conference Center** in Gainesville from May 18-23, 2014. The registration website will open December 2013.

<http://www.phys.ufl.edu/lisasymposiumx/index.html>

## **Backup Slides**

# Concept 1: SGO Mid

LISA-like design with shorter arms, smaller telescope, smaller laser, drift-away orbits...



SGO High (LISA as single-agency) studied as delta

# SGO-High vs Mid (vs LISA baseline)

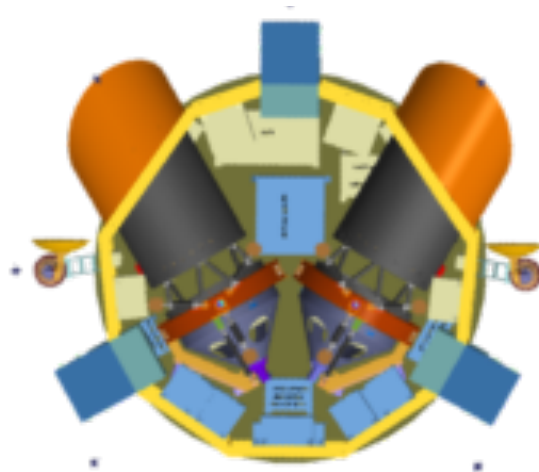
- SGO High differs from LISA by:

- Preserves all LISA performance parameters
- Single agency cost model (not joint mission)
- Lower cost launch vehicle (shared launch on a Falcon Heavy)
- Demonstrated improvements in photoreceiver performance
- More economical trajectories to the operational orbits

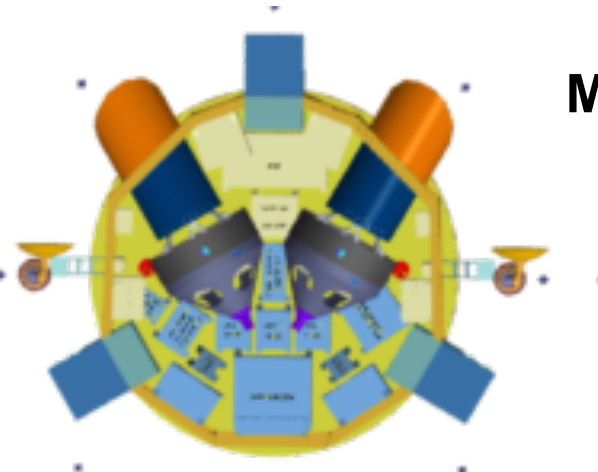
- SGO Mid differs from LISA by:

- Detector arm length reduced from 5 Gm to 1 Gm
- Science operations reduced from 5 to 2 years.
- Nominal starting distance from Earth is reduced by about a factor of 2.5 to a 9-degree trailing orbit.
- Telescope diameter is reduced from 40 to 25 cm, and the laser power out of the telescope is reduced from 1.2 to 0.7 W (end of life).
- In-field guiding is used instead of articulating the entire optical assembly

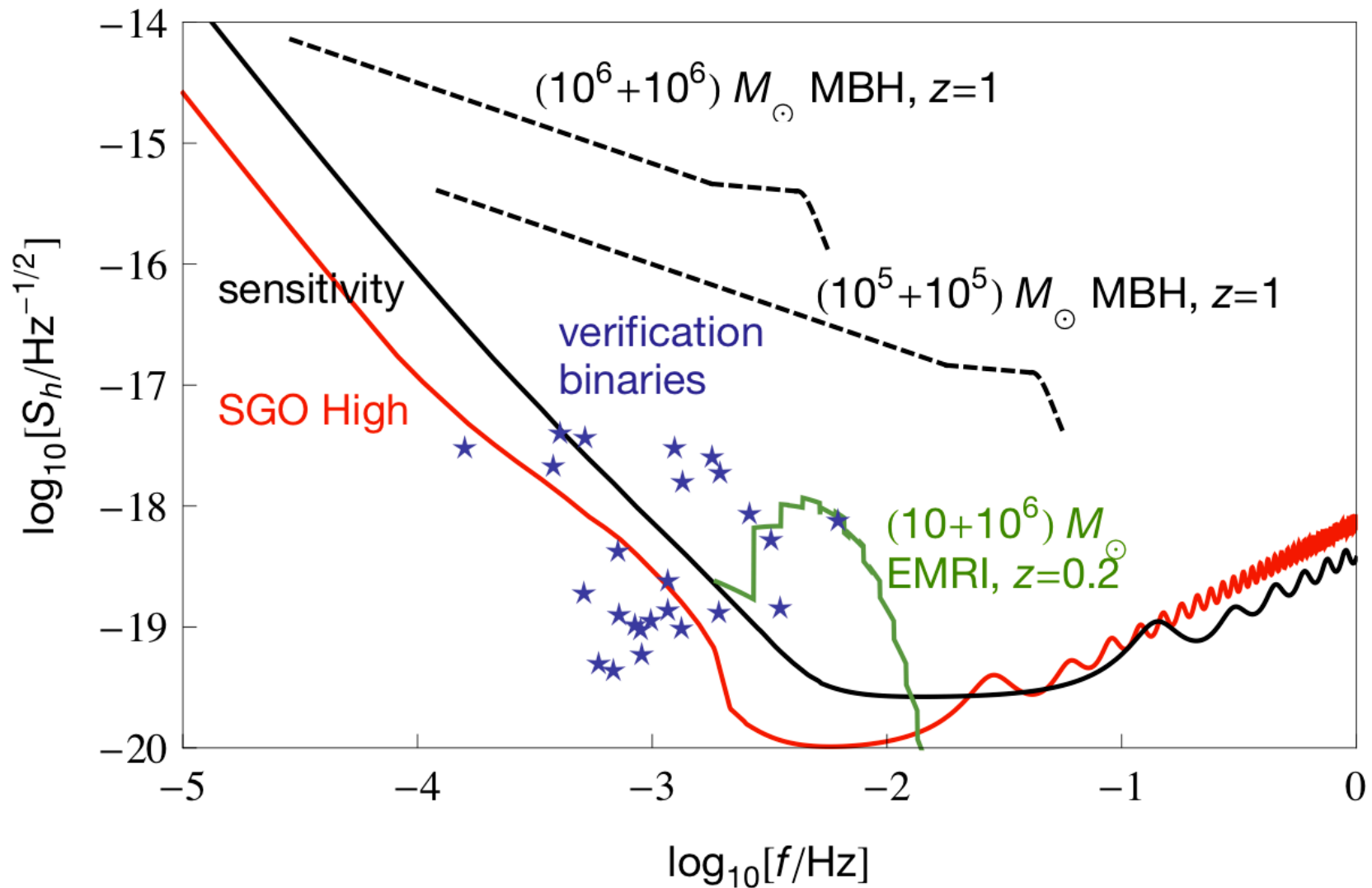
High



Mid



# SGO-Mid Science



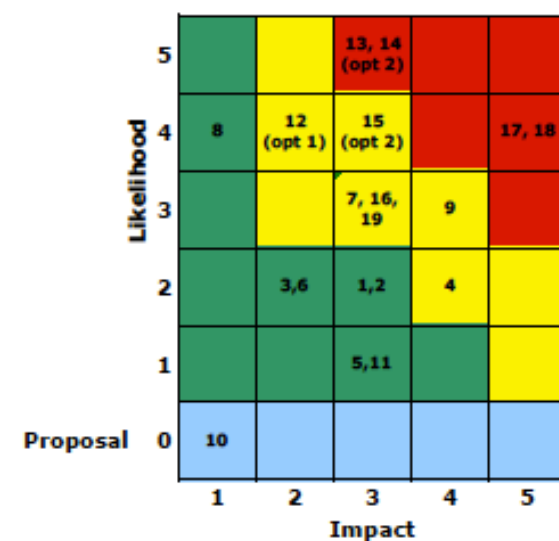
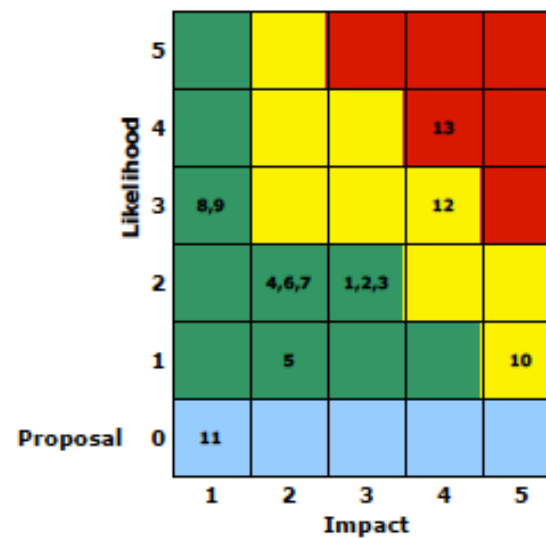
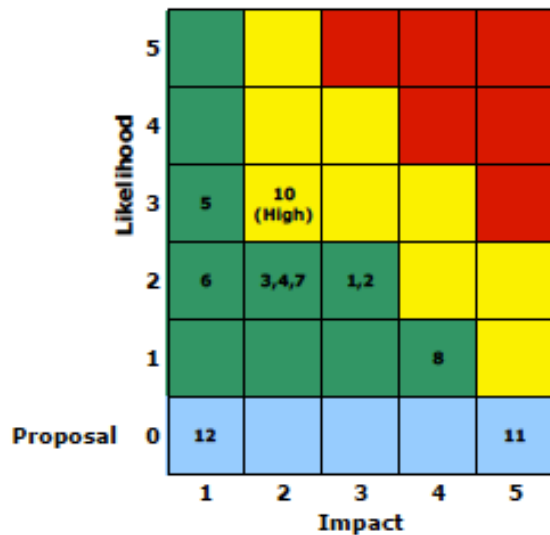
# Risk Assessment: All risks compared

Team X assessment plus Core Team

SGO-Mid/(High)

LAGRANGE

OMEGA



High Risks

Risk	Title	Likelihood	Impact
LAGRANGE-13	Thermal-elastic effects	4	4
OMEGA(2)-13	Staffing/destaffing	5	3
OMEGA(2)-14	Schedule too short	5	3
OMEGA-17	Optical filter required	4	5
OMEGA-18	Fiber phase noise	4	5